



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Food for thought

Citation for published version:

Bonsall, C, Cook, G, Pickard, C, McSweeney, K, Sayle, K, Bartosiewicz, L, Radovanovi, I, Higham, T, Soficaru, A & Boronean, A 2015, 'Food for thought: Re-assessing mesolithic diets in the Iron gates', *Radiocarbon: An International Journal of Cosmogenic Isotope Research*, vol. 57, no. 4, pp. 689-699.
https://doi.org/10.2458/azu_rc.57.18440

Digital Object Identifier (DOI):

[10.2458/azu_rc.57.18440](https://doi.org/10.2458/azu_rc.57.18440)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Radiocarbon: An International Journal of Cosmogenic Isotope Research

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



FOOD FOR THOUGHT: RE-ASSESSING MESOLITHIC DIETS IN THE IRON GATES

Clive Bonsall^{1,2} • Gordon Cook³ • Catriona Pickard¹ • Kathleen McSweeney¹ • Kerry Sayle³ •
László Bartosiewicz⁴ • Ivana Radovanović⁵ • Thomas Higham⁶ • Andrei Soficaru⁷ •
Adina Boroneanț⁸

ABSTRACT. Stable isotope ratios of carbon, nitrogen, and sulfur in human bone collagen are used routinely to aid in the reconstruction of ancient diets. Isotopic analysis of human remains from sites in the Iron Gates section of the Lower Danube Valley has led to conflicting interpretations of Mesolithic diets in this key region of southeast Europe. One view (Bonsall et al. 1997, 2004) is that diets were based mainly on riverine resources throughout the Mesolithic. A competing hypothesis (Nehlich et al. 2010) argues that Mesolithic diets were more varied with at least one Early Mesolithic site showing an emphasis on terrestrial resources, and riverine resources only becoming dominant in the Later Mesolithic. The present article revisits this issue, discussing the stable isotope data in relation to archaeozoological and radiocarbon evidence.

INTRODUCTION

Stable isotope analysis of human bone collagen has become an important method for reconstructing ancient human diets because, unlike the study of associated animal and plant food remains, it provides information on and permits comparisons between individuals. Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios have been the primary tools for interpretation. In the marine environment, $\delta^{13}\text{C}$ values are typically heavier, largely because of fractionation between the atmosphere and the oceans. $\delta^{15}\text{N}$ values for organisms at the top of the foodchain (carnivorous fish and marine mammals) are heavier because of the greater complexity of marine foodwebs combined with a trophic level shift estimated at 3–5‰ (Peterson and Fry 1987). The contrast in values between marine and terrestrial organisms is particularly important for dietary studies in regions where C_3 plants predominate, but becomes more problematic in regions where C_4 plants with much heavier $\delta^{13}\text{C}$ values are a significant component of the vegetation. Distinguishing between diets based on terrestrial and freshwater resources is also possible using C and N stable isotopes where the aquatic foodweb is more complex than that of the neighboring terrestrial environment.

Sulfur isotopes ($\delta^{34}\text{S}$) have been used less frequently in paleodiet studies, but offer several potential advantages over C and N. For example, the balance of research undertaken to date would suggest that there is no significant offset (fractionation) between food and consumer (Nehlich 2015). Also, large differences have been observed between marine (15–20‰) and terrestrial (5‰) diets (Peterson and Fry 1987). However, S occurs in much smaller concentrations in bone collagen than C and N, and most stable isotope laboratories are not set up to analyze S isotopes. Moreover, inconsistent results have been obtained for archaeological samples (e.g. Craig et al. 2006; Privat et al. 2007).

This article reviews the results of dietary stable isotope analyses of human bone collagen from sites in the Iron Gates region. This section of the Lower Danube Valley between Serbia and Romania contains the richest concentration of Mesolithic and Early Neolithic sites in SE Europe. More than 400 burials have been recovered from 15 sites (Figure 1), representing a vast repository of bioarchaeological information on lifestyle, demography, disease, genetic relationships, and diet.

1. School of History, Classics and Archaeology, University of Edinburgh, United Kingdom.

2. Corresponding author. Email: C.Bonsall@ed.ac.uk.

3. SUERC Radiocarbon Dating Laboratory, East Kilbride, United Kingdom.

4. Osteoarchaeological Research Laboratory, University of Stockholm, Sweden.

5. Department of Anthropology, University of Kansas, USA.

6. Research Laboratory for Archaeology and the History of Art, University of Oxford, United Kingdom.

7. ‘Francisc I. Rainer’ Anthropological Research Center, Romanian Academy, București, Romania.

8. ‘Vasile Pârvan’ Institute of Archaeology, Romanian Academy, București, Romania.

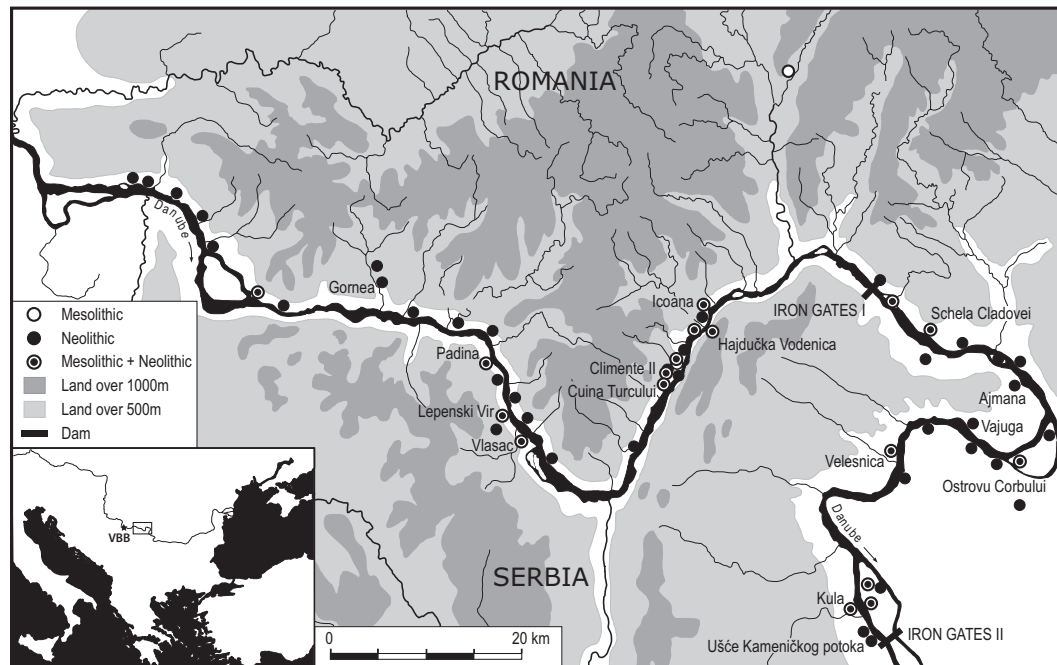


Figure 1 Mesolithic and Early Neolithic sites in the Iron Gates. Named sites have formal burials. Location of Vinča-Belo Brdo (VBB) is shown in the inset [after Boroneanț and Bonsall 2012:Figure 1].

PALEODIET STUDIES IN THE IRON GATES

Carbon and Nitrogen

The first stable isotope research on the Iron Gates Mesolithic and Early Neolithic (Bonsall et al. 1997) presented $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results for burials from Lepenski Vir, Vlasac, and Schela Cladovei. In that initial study, the human bone collagen values were compared with modern analogues for animal and plant resources with appropriate fractionation corrections. Further C and N isotope research on human and animal bone was undertaken by Bonsall et al. (2000, 2004, 2012, 2015), Grupe et al. (2003), Borić et al. (2004, 2008), Borić and Dimitrijević (2007), Borić and Miracle (2004), and Borić and Price (2013). In total, bone collagen C and N stable isotope data were obtained for more than 160 skeletons from 10 sites, spanning the greater part of the Mesolithic to Early Neolithic time range from ~12,200–5500 cal BC. The main conclusions from these studies were that with few exceptions Iron Gates Mesolithic skeletons show elevated $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values, consistent with a diet based on fish and other aquatic resources, while Neolithic samples consistently have lower $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values, but higher than expected for a purely terrestrial diet.

Sulfur

The first paleodiet study for the Iron Gates using sulfur isotopes (Nehlich et al. 2010) presented C, N, and S isotope data for 24 skeletons from four Iron Gates Mesolithic sites (Hajdučka Vodenica, Lepenski Vir, Padina, and Vlasac) and the Neolithic tell settlement of Vinča-Belo Brdo, 72 km up-river from the Iron Gates Gorge, together with equivalent data for the bones of land mammals from Padina and fish from Vlasac (Table 1).

Table 1 Mean $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ values for human and animal bones from Mesolithic and Neolithic sites in the Danube Valley, with period assignment, sample type, and number of specimens analyzed (after Nehlich et al. 2010).

Site	Period assignment	Classification	Σ	$\delta^{13}\text{C} \text{ ‰}$	$\delta^{15}\text{N} \text{ ‰}$	$\delta^{34}\text{S} \text{ ‰}$
Vinča-Belo Brdo	“Middle” Neolithic, 5500–5400 BC	Human	5	-20.7 ± 0.2	11.5 ± 0.8	3.0 ± 0.6
Vlasac	“Early” and “Late” Mesolithic ~8000 BC [1], 7000–6300 BC [3]	Human	4	-19.5 ± 0.6	14.8 ± 0.6	8.9 ± 3.0
Hajdučka Vodenica	“Late” Mesolithic 7000–6000 BC	Human	3	-19.2 ± 0.4	15.8 ± 0.7	9.7 ± 0.8
Padina	“Early Mesolithic” 8700–7800 BC	Human	4	-19.7 ± 0.2	14.4 ± 0.5	4.9 ± 0.6
Lepenski Vir	“Late” Mesolithic to Neolithic >6200 BC to 5500 BC	Human	8	-19.1 ± 0.5	14.9 ± 0.9	8.5 ± 2.6
Padina	—	Terrestrial mammals	4*	-22.0 ± 1.2	6.4 ± 1.3	4.1 ± 1.1
Vlasac	—	Freshwater fish	3	-19.6 ± 0.6	7.3 ± 0.5	14.1 ± 0.1

*Excludes 1 suckling animal.

The human bone $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for the four Mesolithic sites are consistent with previous studies, with $\delta^{15}\text{N}$ generally higher than +14‰ and $\delta^{13}\text{C}$ values generally higher than –20‰. Nehlich et al. (2010) found that the $\delta^{15}\text{N}$ values of the mammals and fish they analyzed were not significantly different, while there was a large and significant difference in the $\delta^{34}\text{S}$ values. From this, they concluded that $\delta^{34}\text{S}$ is a more sensitive measure of the relative importance of terrestrial versus aquatic protein in diet, and proposed the following:

- $\delta^{34}\text{S}$ values of <6‰ reflect a primarily terrestrial diet;
- $\delta^{34}\text{S}$ values of 6–10‰ reflect a mixed terrestrial/aquatic diet; and
- $\delta^{34}\text{S}$ values of >10‰ reflect a primarily aquatic diet.

Thus, Nehlich et al. (2010) interpret the $\delta^{34}\text{S}$ values for Neolithic skeletons from Vinča-Belo Brdo (2.3–3.7‰) as indicative of a diet in which the protein was derived exclusively from terrestrial resources. The $\delta^{34}\text{S}$ values of 4.1–5.7‰ for “Early Mesolithic” skeletons from Padina were interpreted as indicating diets comprising mainly terrestrial mammals with a small percentage of fish. The values for “Late Mesolithic” skeletons from Hajdučka Vodenica, Lepenski Vir, and Vlasac range between 4.4 and 12.7‰, and were seen as reflecting diets that were highly variable, with all three diet types represented at Lepenski Vir and Vlasac, and the “mixed” and “primarily aquatic” diets represented at Hajdučka Vodenica.

DISCUSSION

While in previous studies of the Iron Gates $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for Mesolithic burials have been interpreted as reflecting diets that were consistently high in aquatic protein, the sulfur isotope study by Nehlich et al. (2010) has been used by them to suggest that the “Early Mesolithic” diets (represented by Padina) were relatively low in aquatic protein and “later” Mesolithic diets (represented primarily by Vlasac and Lepenski Vir) were highly variable.

Nehlich et al. (2010) offered two possible explanations for the elevated $\delta^{15}\text{N}$ and low $\delta^{34}\text{S}$ values seen in the humans from Padina and several individuals from Vlasac and Lepenski Vir:

1. *Either* the inclusion of a small amount of fish in an otherwise terrestrial-based diet;
2. *Or* an entirely terrestrial diet with regular consumption of meat from suckling herbivores.

What constitutes a “small amount” of fish was not made clear. However, using $\delta^{34}\text{S}$ values of +4.0‰ and +14.0‰ as the 100% terrestrial and aquatic diet end members, respectively (based on Nehlich et al.’s data for wild herbivores and fish, and assuming no isotopic shift between diet and consumer), the $\delta^{34}\text{S}$ values of the Padina humans would imply aquatic contributions to dietary protein of between 1% and 17%. These percentages seem low given the average $\delta^{15}\text{N}$ value of $14.4 \pm 0.5\text{‰}$ for the Padina humans (Table 1). The $\delta^{15}\text{N}$ average of three wolves (*Canis lupus*) from Vlasac is $10.5 \pm 1.2\text{‰}$ (Grupe et al. 2003). If wolves can be considered a proxy for humans subsisting predominantly on a diet of terrestrial animal meat, then a substantial input of freshwater fish would likely be required to raise $\delta^{15}\text{N}$ above 14‰.

While regular consumption of suckling mammals could, in theory, account for the combination of high $\delta^{15}\text{N}$ and low $\delta^{34}\text{S}$ in Iron Gates skeletons, such an explanation is not supported by archaeozoological evidence. Even allowing for taphonomic loss, no Iron Gates Mesolithic site or context shows an outstanding frequency of suckling-age animals. Farmers, and especially herders, are likely to have had at least as much access to meat from suckling animals as any group of hunter-gatherers, yet we are not aware of any prehistoric farming/herding society from temperate Europe, with limited access to aquatic resources, that shows $\delta^{15}\text{N}$ values approaching those of Iron Gates Mesolithic people. For example, Early Bronze Age pastoralists from the Carpathians have average $\delta^{15}\text{N}$ values of $10.7 \pm 0.7\text{‰}$ (Bonsall, unpublished data).

Nehlich et al. (2010) interpreted the stable isotope profile of the Neolithic humans from Vinča-Belo Brdo—extremely low $\delta^{34}\text{S}$ values combined with $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values lighter than those for Mesolithic Padina—as indicative of diets based on terrestrial mammals. However, the Vinča $\delta^{15}\text{N}$ values are unusually heavy for Starčevo burials (and Neolithic farmers in general), matched only by those from riverine sites (e.g. Velesnica in Serbia and Maroslele-Pana in Hungary) where fish consumption is documented or suspected (Bonsall et al. 2007, 2015). Given the location of Vinča-Belo Brdo immediately adjacent to the Danube and the presence on the site of fish and shellfish remains (Dimitrijević 2006), it would be surprising if aquatic resources were not a regular part of the Neolithic diet. Unless the (terrestrial) dietary baseline at Neolithic Vinča can be shown to have been unusually enriched (currently there are no baseline data for Vinča), the $\delta^{15}\text{N}$ range of $11.5 \pm 0.8\text{‰}$ could be interpreted as including a contribution from aquatic resources.

There are several limitations of the study by Nehlich et al. (2010) that constrain further discussion of their stable isotope data. Only 3 of the 24 individuals had been dated directly, one each from Hajdučka Vodenica, Padina, and Vlasac (Table 2). Estimated dates were assigned to the other 21 skeletons based on criteria that were not fully explained (Table 1). Six of the eight skeletons analyzed from Lepenski Vir were assigned to the period 6200–6000 cal BC, presumably because many published ^{14}C dates on short-lived materials (animal and human bones) from the site fall into this period (Borić and Dimitrijević 2007; Bonsall et al. 2008), although it was acknowledged that two of these six burials might be older than 6200 cal BC. The other two burials (68 and 74) from Lepenski Vir were assigned to the period 5900–5500 cal BC, most likely because both burials are described in unpublished field documentation as “crouched” or “flexed” inhumations, which is the characteristic body position for Early Neolithic (Starčevo–Körös–Criş culture) burials from the Balkans. This

chronology should be treated with caution. Previous studies have shown that by no means all burials from Lepenski Vir belong to the Final Mesolithic–Early Neolithic time range (6200–5500 cal BC). There is evidence of both earlier and later activity on the site, with direct ^{14}C dates on human remains ranging from ~8900 cal BC to cal AD 1450 (Bonsall et al. 2008, 2015). Moreover, body position is not an infallible guide to the date of a burial. Although flexed inhumations are much more frequent in the Neolithic, there are a number examples from Iron Gates sites that are probably Mesolithic in date (see e.g. Boroneanț 1970; Srejović and Letica 1978). It is also worth noting that burials 68 and 74 from Lepenski Vir have $\delta^{15}\text{N}$ values higher than +14‰, and such elevated $\delta^{15}\text{N}$ values are highly unusual in adult humans from the Iron Gates dated to the period after 5900 cal BC.

Table 2 AMS and radiometric radiocarbon dates for human bone samples included in the study by Nehlich et al. (2010). The stable C, N, and S isotope values are those provided by Nehlich et al. (2010:Table 3). Reservoir-corrected ages were calculated using Method 1 of Cook et al. (2002), in the case of AA-57776 and OxA-13613 using the $\delta^{15}\text{N}$ values provided by the radiocarbon laboratories rather than those measured by Nehlich et al. (2010). The calibrated age ranges are quoted with endpoints rounded outwards to 5 yr, following Mook (1986). The ranges have been calculated using the maximum intercept method (Stuiver and Reimer 1986), the IntCal13 calibration curve (Reimer et al. 2013), and the computer program OxCal v 4.2.3 (Bronk Ramsey 2009).

Sample ID	Site	Context	Lab ID	^{14}C age (BP)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	Corrected age (BP)	Calibrated age BC (95% confidence)	Median probability
IG-P-4	Padina	Burial 12	BM-1146	9331 ± 58 ^a	−19.5	14.5	5.0	8943 ± 77	8289–7831	8095
IG-V-1	Vlasac	Burial 17	AA-57776	9353 ± 86 ^b	−20.0	14.3	5.8	8927 ± 102	8298–7741	8066
IG-HV-3	Hajdučka Vodenica	Burial 8	OxA-13613	8456 ± 37 ^c	−19.3	15.6	8.8	7949 ± 75	7051–6655	6860

Source of ^{14}C data: ^aBurleigh and Matthews 1982; ^bBorić et al. 2008; ^cBorić 2011.

A further limitation of the study by Nehlich et al. (2010) is the small amount of comparative data they obtained for potential food sources (Table 1). $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ results are presented for just five terrestrial mammals (all wild species) and three fish (only identified at the family level: two cyprinids and one acipenserid). The $\delta^{15}\text{N}$ values of the mammals ($6.4 \pm 1.3\text{‰}$) and fish ($7.3 \pm 0.5\text{‰}$) are similar, although this could be a function of sample size and/or species composition. No catfish were included in the fish sample, and it is not known if the single acipenserid is the small freshwater sterlet (*Acipenser ruthenus*) or one of the larger, anadromous sturgeon species whose bones occur on archaeological sites in the Iron Gates (Bartosiewicz et al. 2008). Also, no information is provided on the size of the fish that were analyzed; catfish and sturgeon become more carnivorous as they grow larger, and the bones of large specimens can be expected to show more enriched $\delta^{15}\text{N}$ values. Data compiled from previous studies (Bonsall et al. 1997, unpublished; Whittle et al. 2002; Grupe et al. 2003; Borić and Miracle 2004; Borić and Price 2013) show significant differences in N isotope ratios between the bones of terrestrial mammals and fish recovered from Iron Gates sites. The mean $\delta^{15}\text{N}$ for wild ungulates is $6.1 \pm 1.3\text{‰}$ ($n = 62$), compared to $9.0 \pm 1.9\text{‰}$ for fish ($n = 16$), with the highest values recorded for catfish and anadromous sturgeon (up to 12.9‰).

In addition, the three fish bones analyzed are from a single site (Vlasac) *within* the Iron Gates Gorge; no fish were analyzed from Vinča-Belo Brdo, and no information on the chronological context(s) of the samples is available. By using the fish bone isotope data from Vlasac as the basis for interpreting human bone collagen S isotope results from all the sites in their study, Nehlich et al. (2010) assumed, in effect, that (1) the three fish of unknown date from Vlasac are representative of the S isotope composition of fish in the River Danube; (2) the S isotope composition of fish did not vary significantly along the course of the Danube between Vinča-Belo Brdo and Vlasac, a distance of ~145 km; and (3) the S isotope composition of Danube fish remained more-or-less uniform over

the time period represented by all the human skeletons analyzed (at least 3 millennia). In a recent study of early Viking age settlement of Iceland, Sayle et al. (2015) noted that exploiting $\delta^{34}\text{S}$ was a valuable, additional tool for determining paleodiets; however, they also stated that it was wrong to assume that animals reared near to one archaeological site will have similar $\delta^{34}\text{S}$ values to the same species raised at a closely neighboring site. They noted an approximate 6‰ enrichment in animals at one site compared to another where these sites were only 10 km apart and with the same underlying geology.

Table 3 Stable isotope data for 24 skeletons from the Lower Danube Valley, ordered according to $\delta^{34}\text{S}$ value, with division into groups identified by hierarchical cluster analysis (after Nehlich et al. 2010).

Group	Case	Label (Site)	Description	Variables		
				$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	$\delta^{34}\text{S}$ ‰
I	17	Vlasac	Burial 70	−18.7	15.5	12.7
	13	Lepenski Vir	Burial 104	−19.5	16.0	10.9
	12	Lepenski Vir	Burial 11	−18.6	15.8	10.8
	7	Lepenski Vir	Burial 45a	−18.3	15.3	10.6
	18	Hajdučka Vodenica	Burial 22	−18.7	16.5	10.3
	19	Hajdučka Vodenica	Burial 23–25	−19.6	15.1	10.1
	16	Vlasac	Burial 11a	−19.5	14.5	10.0
	8	Lepenski Vir	Burial 13	−19.4	15.4	9.9
	11	Lepenski Vir	Burial 100	−18.7	13.6	8.9
	20	Hajdučka Vodenica	Burial 8	−19.3	15.6	8.8
II	15	Vlasac	Burial 16	−19.9	15.0	7.3
	6	Lepenski Vir	Burial 68	−19.7	14.6	6.8
	14	Vlasac	Burial 17	−20.0	14.3	5.8
	23	Padina	Burial 19a	−20.0	13.7	5.7
	9	Lepenski Vir	Burial 74	−19.5	14.4	5.5
	22	Padina	Burial 12	−19.5	14.5	5.0
	21	Padina	Burial 16	−19.6	14.9	4.9
	10	Lepenski Vir	Burial 67	−19.4	13.8	4.4
	24	Padina	Disarticulated skull	−19.7	14.6	4.1
III	3	Vinča-Belo Brdo	Skull VI	−20.9	11.1	3.7
	2	Vinča-Belo Brdo	Skull V	−20.7	11.8	3.2
	1	Vinča-Belo Brdo	Skull II	−20.4	12.2	3.1
	4	Vinča-Belo Brdo	Skull VII	−20.9	12.0	2.5
	5	Vinča-Belo Brdo	Skull VIII	−20.6	10.3	2.3

These assumptions need to be tested. The S isotope composition of a fish is similar to that of its diet, which in turn reflects that of the aqueous environment; thus, marine fish have $\delta^{34}\text{S}$ values close to those of ocean water sulfate ($\sim +21$ ‰). The $\delta^{34}\text{S}$ values of dissolved sulfate in river water are generally much lower than those in the sea, but can vary significantly along a river course according to the subcatchment geology (cf. Hitchon and Krouse 1972). There is also the possibility of significant fluctuations in the geochemistry of a river through time in response to changes in climate, soils, and vegetation within its catchment. In the case of the prehistoric Danube, further complexity is introduced because the fish consumed by Mesolithic and Neolithic people living in the Iron Gates comprised not only those species that were permanently resident in the Danube (e.g. carp and catfish), but also anadromous species (especially sturgeons) that lived most of their lives in the Black Sea but periodically migrated along the river to breed. The latter would carry the Black Sea $\delta^{34}\text{S}$ signal rather than that of the river reach where they were caught. The proportion of anadromous fish entering the human diet likely varied along the course of the Danube according to local river conditions and

human fishing practices (Bartosiewicz et al. 2008:Figures 7–8), and could have changed through time in response to environmental fluctuations and changing subsistence patterns.

With these caveats in mind, it is possible to offer an alternative interpretation of the human bone collagen stable isotope data presented by Nehlich et al. (2010). A hierarchical cluster analysis was performed on the stable C, N, and S isotope results from the 24 skeletons (Table 3) from Hajdučka Vodenica, Lepenski Vir, Padina, Vlasac, and Vinča-Belo Brdo. The resulting dendrogram suggests there are three main groups within the data (Figure 2):

- I. Individuals with high $\delta^{34}\text{S}$ (8.8–12.7‰) and high $\delta^{15}\text{N}$ (13.6–16.5‰);
- II. Individuals with moderate $\delta^{34}\text{S}$ (4.4–7.3‰) and high $\delta^{15}\text{N}$ (13.8–15.0‰); and
- III. Individuals with low $\delta^{34}\text{S}$ (2.3–3.7‰) and moderate $\delta^{15}\text{N}$ (10.3–12.2‰).

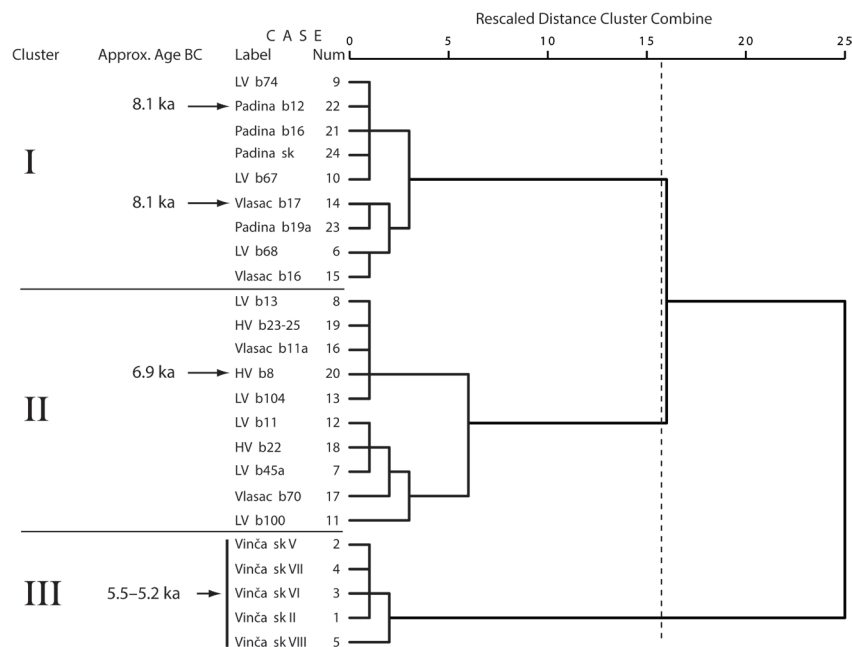


Figure 2 Dendrogram grouping 24 skeletons from sites in the Danube Valley according to their $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ values (cf. Table 3), using Ward linkage. Approximate calibrated BC ages are shown for individuals in each of the main groups (cf. Table 2). Key: LV – Lepenski Vir; HV – Hajdučka Vodenica; b – burial; sk – skull.

The Group III individuals are all from Vinča-Belo Brdo, and are also distinguished from the other two groups in having lighter C isotope ratios. Group II comprises individuals from all four Iron Gates sites, while other individuals from three of these sites (Hajdučka Vodenica, Lepenski Vir, and Vlasac) form Group I. The same groupings are evident in the bivariate plot of $\delta^{34}\text{S}$ and $\delta^{15}\text{N}$ (Figure 3).

There are no direct ^{14}C dates for any of the five individuals in Group III. They were part of a collective burial of nine individuals in the lowermost level of the Vinča-Belo Brdo site, although there is debate over whether this feature was associated with a Starčevo culture occupation or was intrusive during the later Vinča culture phase (for discussion, see Borić 2009). Based on ^{14}C dating of asso-

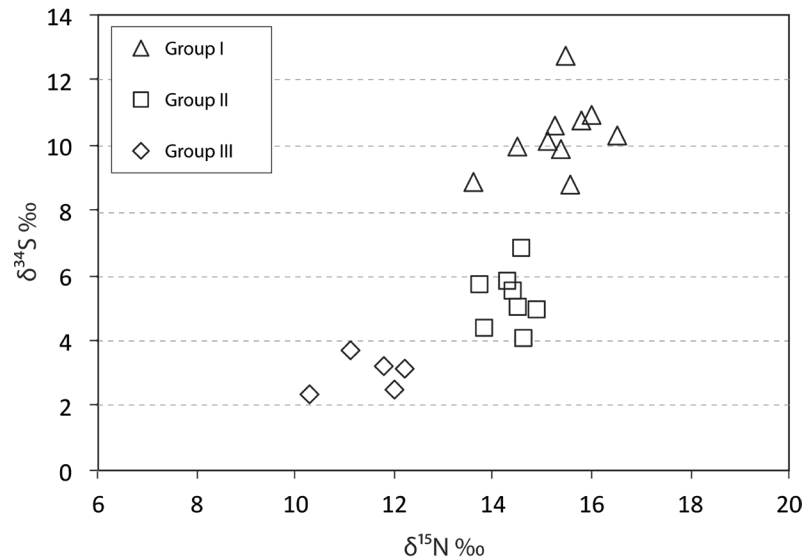


Figure 3 Bivariate plot of $\delta^{34}\text{S}$ and $\delta^{15}\text{N}$ distinguished by group

ciated human remains (Borić 2009), a Neolithic date between ~5500 and 5200 cal BC may be suggested. Nehlich et al.'s (2010:1133) estimated date corresponds to the early part of this time range. There is a single ^{14}C -dated individual in Group II (Hajdučka Vodenica burial 8) with a calibrated age of ~6400 cal BC after correction for the Danube reservoir effect (cf. Cook et al. 2002). In Group I, there are two individuals with direct ^{14}C dates—Vlasac burial 17 and Padina burial 12—both dating to ~8100 cal BC after reservoir correction (Table 2).

While it would be premature to draw firm conclusion on the basis of so few directly dated skeletons, the data at least suggest that the groupings identified by cluster analysis relate to different time periods, with Group I dating to the earlier Mesolithic, Group II to the later Mesolithic, and Group III to the Neolithic. If this provisional interpretation proves to be correct, then it would indicate that Nehlich et al.'s "estimated dates" for some of the burials from Hajdučka Vodenica, Lepenski Vir, and Vlasac are in error. It would also contradict their assertion that the people buried at Lepenski Vir and Vlasac came from communities with highly variable diets, since the range of C and N isotope values between the members of each chronological group is no greater than we would expect within a population of individuals with similar diets (cf. Schoeninger and DeNiro 1984).

The $\delta^{15}\text{N}$ profiles of Groups I and II suggest the members of both groups consumed substantial amounts of fish over their lifetimes. However, the $\delta^{34}\text{S}$ values are significantly higher for Group I. Possible explanations for this pattern include an increase in the consumption of marine fish (e.g. Black Sea sturgeon) in the later Mesolithic, and/or a change in the geochemistry of the Danube–Black Sea system. It has been argued elsewhere (Cook et al. 2009) that sturgeon increased in economic importance in the later Mesolithic of the Iron Gates, and their ideological importance in the period after 6300 cal BC is clearly reflected in the appearance at Lepenski Vir of stone sculptures with sturgeon-like features (cf. Radovanović 1997).

CONCLUSIONS

The aim of this paper has been to re-examine the results of a previous study of Mesolithic and Neolithic human remains combining C, N, and S isotopes. It is undoubtedly the case that the research by Nehlich et al. (2010) is a landmark study that has demonstrated that S can be a valuable adjunct

to C and N for assessing the dietary importance of aquatic resources, and may be a more sensitive indicator of riverine inputs. Their study undoubtedly suggests that, whenever possible, $\delta^{34}\text{S}$ analysis should be carried out routinely in paleodiet studies. However, Nehlich et al.'s study does suffer from an inadequate chronological framework and a lack of detailed information on the local foodweb. We have disregarded their estimated dates for the human remains from the Iron Gates sites and relied instead on the few direct age measurements available, although we have adopted an estimated age range for Vinča where the chronological context is more tightly constrained.

Our re-analysis of their data suggests there is an underlying temporal trend in the stable isotope results, which is particularly evident for $\delta^{34}\text{S}$. However, this can only be demonstrated conclusively by paired stable isotope and ^{14}C analyses of a much larger number of samples from the current data set. It should be stressed, however, that the chronological pattern is unlikely to be absolute because of the possibility of the inclusion of immigrants with different dietary patterns (cf. Bonsall et al. 2004, 2008; Borić and Price 2013).

Interpretation of stable isotope data from sites along the Middle and Lower Danube is made more complex by the fact that the fish resources available to prehistoric populations included both freshwater and marine species, and because we have virtually no information on how $\delta^{34}\text{S}$ values varied along the paleo-Danube according to geochemistry. Therefore, it would be premature to conclude that $\delta^{34}\text{S}$ data necessarily contradict previous interpretations of prehistoric dietary patterns in the Iron Gates obtained from $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements. Our provisional conclusion is that the S data actually reinforce the patterns observed for C and N. For example, in our previous work using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements, we observed a weak distinction between earlier and later Mesolithic diets, with a significant overlap in the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ranges. Nehlich et al.'s data show a similar overlap in the C and N ranges, but a clear distinction in the S isotope ranges. It is evident therefore that in addition to paired ^{14}C and stable isotope analyses of human bone collagen, paired ^{14}C and stable isotope analyses of food remains (fish bones, mammalian bones, and plant residues) are required for successful reconstruction of ancient diets. At the time of our early publications on dietary reconstruction within the Iron Gates, the linear interpolation between $\delta^{15}\text{N}$ dietary end-member values to determine the level of consumption of aquatic resources, based on human bone collagen measurements, was the best method available, especially given that nitrogen does not occur to any degree in carbohydrates and fats. However, the development of software programs such as the Bayesian dietary mixing model FRUITS (*Food Reconstruction Using Isotopic Transferred Signals*) (Fernandes et al. 2014) presents a much more sophisticated method of dietary reconstruction that we are currently pursuing through stable isotope measurements on both animal and human remains.

ACKNOWLEDGMENTS

We are grateful to Vesna Dimitrijević and Nenad Tasić for information about the fish and shellfish remains from the recent excavations at Vinča-Belo Brdo. Thanks also to Olaf Nehlich and an anonymous referee for their constructive comments.

REFERENCES

- Bartosiewicz L, Bonsall C, Şişu V. 2008. Sturgeon fishing in the Middle and Lower Danube region. In: Bonsall C, Boroneanţ V, Radovanović I, editors. *The Iron Gates in Prehistory*. Oxford: Archaeopress. p 39–54.
- Bonsall C, Lennon R, McSweeney K, Stewart C, Harkness D, Boroneanţ V, Bartosiewicz L, Payton R, Chapman J. 1997. Mesolithic and Early Neolithic in the Iron Gates, a palaeodietary perspective. *Journal of European Archaeology* 5:50–92.
- Bonsall C, Cook G, Lennon R, Harkness D, Scott M, Bartosiewicz L, McSweeney K. 2000. Stable isotopes, radiocarbon and the Mesolithic–Neolithic transition in the Iron Gates. *Documenta Praehistorica* 27:119–32.
- Bonsall C, Cook GT, Hedges REM, Higham TFG, Pick-

- ard C, Radovanović I. 2004. Radiocarbon and stable isotope evidence of dietary change from the Mesolithic to the Middle Ages in the Iron Gates: new results from Lepenski Vir. *Radiocarbon* 46(1):293–300.
- Bonsall C, Radovanović I, Roksandic M, Cook GT, Higham TFG, Pickard C. 2008. Dating burial practices and architecture at Lepenski Vir. In: Bonsall C, Boroneanț V, Radovanović I, editors. *The Iron Gates in Prehistory*. Oxford: Archaeopress. p 175–204.
- Bonsall C, Boroneanț A, Soficaru A, McSweeney K, Higham T, Mirițoiu N, Pickard C, Cook GT. 2012. Interrelationship of age and diet in Romania's oldest human burial. *Naturwissenschaften* 99(4):321–5.
- Bonsall C, Vasić R, Boroneanț A, Roksandic M, Soficaru A, McSweeney K, Evatt A, Agurauia U, Pickard C, Dimitrijević V, Higham T, Hamilton D, Cook G. 2015. New AMS ^{14}C dates for human remains from Stone Age sites in the Iron Gates reach of the Danube, southeast Europe. *Radiocarbon* 57(1):33–46.
- Borić D. 2009. Absolute dating of metallurgical innovations in the Vinča culture of the Balkans. In: Kienlin TK, Roberts BW, editors. *Metals and Societies. Studies in Honour of Barbara S. Ottaway*. Bonn: Habelt. p 191–245.
- Borić D. 2011. Adaptations and transformations of the Danube Gorges foragers (c. 13,000–5500 cal. BC): an overview. In: Krauß R, editor. *Beginnings – New Research in the Appearance of the Neolithic Between Northwest Anatolia and the Carpathian Basin*. Rahden/Westfalen: Leidorf. p 157–203.
- Borić D, Dimitrijević V. 2007. Absolute chronology and stratigraphy of Lepenski Vir. *Starinar* 57:9–55.
- Borić D, Miracle P. 2004. Mesolithic and Neolithic (dis)continuities in the Danube gorges: new AMS dates from Padina and Hajdučka Vodenica (Serbia). *Oxford Journal of Archaeology* 23(4):341–71.
- Borić D, Price TD. 2013. Strontium isotopes document greater human mobility at the start of the Balkan Neolithic. *Proceedings of the National Academy of Sciences of the USA* 110(9):3298–303.
- Borić D, Grupe G, Peters J, Mikić Ž. 2004. Is Mesolithic–Neolithic subsistence dichotomy real? New stable isotope evidence from the Danube Gorges. *European Journal of Archaeology* 7(3):221–48.
- Borić D, French C, Dimitrijević V. 2008. Vlasac revisited: formation processes, stratigraphy and dating. *Documenta Praehistorica* 35:261–87.
- Boroneanț A, Bonsall C. 2012. Burial practices in the Iron Gates Mesolithic. In: Kogălniceanu R, Curcă R, Gligor M, Stratton S, editors. *HOMINES, FUNERA, ASTRA. Proceedings of the International Symposium on Funerary Anthropology 5–8 June 2011 '1 Decembrie 1918' University (Alba Iulia, Romania)*. Oxford: Archaeopress. p 45–56.
- Boroneanț V. 1970. Un mormint din perioada de trecere de la Paleolitic Superior la Epipaleolitic. *Studii și Cercetări de Istorie Veche* 21:129–32.
- Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–60.
- Burleigh R, Matthews K. 1982. British Museum natural radiocarbon measurements XIII. *Radiocarbon* 24(2):151–70.
- Cook GT, Bonsall C, Hedges REM, McSweeney K, Boroneanț V, Bartosiewicz L, Pettitt P. 2002. Problems of dating human bones from the Iron Gates. *Antiquity* 76(291):77–85.
- Cook GT, Bonsall C, Pickard C, McSweeney K, Bartosiewicz L, Boroneanț A. 2009. The Mesolithic–Neolithic transition in the Iron Gates, Southeast Europe: calibration and dietary issues. In: Crombé Ph, Van Strydonck M, Sergeant J, Bats M, Boudin M, editors. *Chronology and Evolution within the Mesolithic of North-West Europe. Proceedings of an International Meeting, Brussels, May 30th–June 1st 2007*. Newcastle upon Tyne: Cambridge Scholars Publishing. p 519–37.
- Craig OE, Ross R, Andersen SH, Milner N, Bailey GN. 2006. Focus: sulphur isotope variation in archaeological marine fauna from northern Europe. *Journal of Archaeological Science* 33(11):1642–6.
- Dimitrijević V. 2006. Vertebrate fauna of Vinča-Belo Brdo (excavation campaigns 1998–2003). *Starinar* 56:245–69.
- Fernandes R, Millard AR, Brabec M, Nadeau M-J, Grootes P. 2014. Food Reconstruction Using Isotopic Transferred Signals (FRUITS): a Bayesian model for diet deconstruction. *PLoS ONE* 9(2):e87436.
- Grupe G, Mikić Z, Peters J, Manhart H. 2003. Vertebrate food webs and subsistence strategies of Meso- and Neolithic populations of Central Europe. In: Grupe G, Peters J, editors. *Decyphering Ancient Bones*. Rahden/Westfalen: Leidorf. p 193–213.
- Hitchon B, Krouse HR. 1972. Hydrogeochemistry of the surface waters of the Mackenzie River drainage basin, Canada—III. Stable isotopes of oxygen, carbon and sulphur. *Geochimica et Cosmochimica Acta* 36(12):1337–57.
- Mook WG. 1986. Business meeting: recommendations/resolutions adopted by the Twelfth International Radiocarbon Conference. *Radiocarbon* 28(2A):799.
- Nehlich O. 2015. The application of sulphur isotope analyses in archaeological research: a review. *Earth Science Reviews* 142:1–17.
- Nehlich O, Borić D, Stefanović S, Richards MP. 2010. Sulphur isotope evidence for freshwater fish consumption: a case study from the Danube Gorges, SE Europe. *Journal of Archaeological Science* 37(5):1131–9.
- Peterson BJ, Fry B. 1987. Stable isotopes in ecosystem studies. *Annual Review of Ecology and Systematics* 8:293–320.
- Privat KL, O'Connell TC, Hedges REM. 2007. The distinction between freshwater- and terrestrial-based diets: methodological concerns and archaeological applications of sulphur stable isotope analysis. *Journal of Archaeological Science* 34(8):1197–204.
- Radovanović I. 1997. The Lepenski Vir culture: a contribution to interpretation of its ideological aspects. In: Lazić M, editor. *Antidoron. Completis LXV annis*

- Dragoslavo Srejšović ab amicis collegis discipulis oblatum*. Belgrade: Centre for Archaeological Research. p 87–93.
- Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hatté C, Heaton TJ, Hoffman DL, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Staff RA, Turney CSM, van der Plicht J. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55(4):1869–87.
- Sayle KL, Hamilton WD, Cook GT, Ascough PL, Gestsdóttir H, McGovern TH. 2015. Deciphering diet and monitoring movement: multiple stable isotope analysis of the Viking Age settlement at Hofstaðir, Lake Mývatn, Iceland. *American Journal of Physical Anthropology* (accepted).
- Schoeninger M, DeNiro MJ. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48(4):625–39.
- Srejšović D, Letica Z. 1978. *Vlasac. A Mesolithic Settlement in the Iron Gates. Volume I, Archaeology*. Belgrade: Serbian Academy of Sciences and Arts.
- Stuiver M, Reimer P. 1986. A computer program for radiocarbon age calculation. *Radiocarbon* 28(2B):1022–30.
- Whittle A, Bartosiewicz L, Borić D, Pettitt P, Richards M. 2002. In the beginning: new radiocarbon dates for the Early Neolithic in northern Serbia and south-east Hungary. *Antaeus* 25:63–117.